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The Effect of Vibration Amplitude and Frequency on the Fatigue Life

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Abstract - *In this paper, the relationship between vibration and fatigue life of metal has been investigated. To perform the research, finite element method is used to design two types of steel specimen before the experiment under bending load is conducted on an electro dynamic shaker. In the experiment, the tested frequenciesare around the first natural frequency of the specimens and they are carried out at the frequency ratios r = f/fn (f = excitation frequency, fn = natural frequency) = 0.9010, 0.9792, 1.0000, 1.0200, 1.0900. The frequency ratio is used instead of frequency in order to get rid of the error occurs because the first natural frequencies of the specimens are not exactly the same. The amplitude of the vibration is conducted at the constant acceleration of 10g (g = 9.81m/s^2). The results from both finite element method and experiment show that at the constant acceleration with respect to the variation of frequency ratio, the fatigue life increases as the frequency ratio increases.*

Keywords: Vibration amplitude, Frequency, Fatigue life.

1. INTRODUCTION

The term fatigue has been the subject of engineering topics for more than 150 years ago. In 1828, the early study was W.A.J Albert, who tested mine hoist chains under cyclic loading in Germany. After that, the first one who introduced the word fatigue was J.V. Poncelet who published a book in 1839. Fatigue was further discussed and studied in several countries due to failures of the mechanical components such as railway axles, shaft, gear, bridge girder, gas turbine etc. Furthermore, the well-known investigator in fatigue failure was the German engineer, August Wohler who had designed the structure to avoid fatigue failure; he also tested irons, steels, and other metals under bending, torsion, and axial loads. Moreover, he also demonstrated that fatigue was affected by both cyclic stresses and steady (mean) stresses (Norman). Fatigue is initiated by the cyclic loading (repeated load), static load, temperature,corrosion, and other important thing that affects fatigue failure is vibration. The term vibration is characterized by amplitude and frequency. When a machine or other component runs at the natural frequency, i.e. its resonance frequency, the amplitude of vibration is high and this component tends to damage or failure rapidly.

Several researchers have investigated about fatigue and vibration (SECIL, 2004;Rahman, 2009; Dwi, 2011). The authors of Dwi, (2011) investigated and calculated the fatigue life of the aluminum cantilever plate subjected in random vibration in time domain and frequency domain by using the method of rainflow cycle counting. A mechanical structure subjected to random loading can lead to fatigue, thus the fatigue can be predicted when it is subjected to random excitation load by conducting frequency analysis (Dwi, 2011). In (Rahman, 2009), the fatigue life of a new piston is predicted by using finite element method when a random load due to vibration was applied.

The objective of this study is to investigate the vibration amplitude and frequency on the fatigue life of steel specimens when the constant acceleration and

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varying frequencies are applied in order to get the fatigue life in both of theory as well as experiment.

This paper is organized as follows. In section 2 modeling the specimens in finite element method software (Nastran) to determine the stress and of course, the fatigue life can be manipulated by using finite element method. In section 3 the experimental results obtained from constant acceleration (10g) and variation of frequency ratios. Finally, the conclusion can be drawn in section 4.

2. MODELING OF THE SPECIMENS

2.1Dimension and Properties of the Specimens

In this research, there are two types of specimens to be designed and tested. The dimension of these specimens (in mm) is shown in Figure 1&2 with material properties as bellow (material testing laboratory) :

Material: Steel
Young modulus, E= 205 GPa,
Mass density = 7850 kg/m3,
Poisson's ratio = 0.29,
Yield strength = 289.40 MPa
Ultimate strength = 362.654 MPa

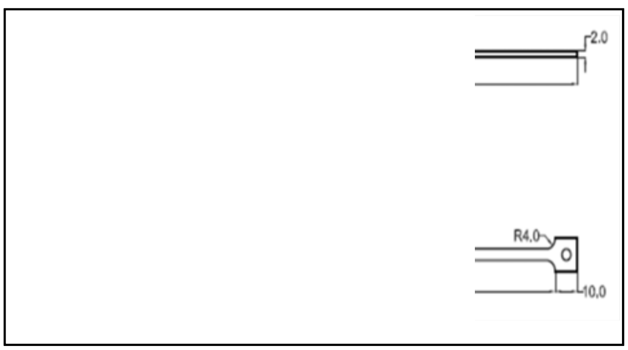

Fig.1. Dimension of the first type specimen

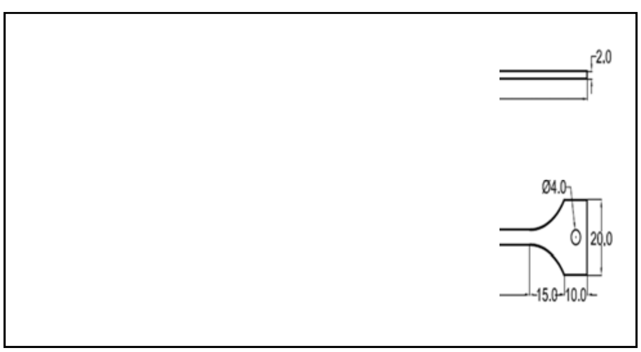

Fig.2. Dimension of the second type specimen

In order to check which chemical compositions affect to the fatigue life of the specimens, the tested chemical compositions is done and the result is demonstrated in Table 1.

Table 1: Chemical composition in the specimen

C (%)	0.05915
Si (%)	0.0153
S (%)	0.00342
P (%)	0.0106
Mn (%)	0.32766
Ni (%)	0.01328
Cr (%)	0.0227
Mo (%)	0.00009
Ti (%)	0.00185
Sn (%)	0.00107
Al (%)	0.04993
Pb (%)	0.0011
Zn (%)	0.00135
Cu (%)	0.01797
Fe(%)	99.4801

According to the reference, the composition which affects to the fatigue life of the specimens is lead (Pb). However, the Pb content in the specimen is very small indeed (0.0011%) so no estimation concerning the fatigue life can be made.

2.2. First natural frequency of the specimens

Based on the material properties, dimension of the specimens and the mass of 20 gram which is mounted at the end of each side of the specimen considered as load, thus the first natural frequency of the first and second type specimens obtained from the finite element method software is 41.29 Hz, 43.79 Hz respectively as shown in the Fig.3& 4.

Fig.3.The first natural frequency of the first type specimen

Fig.4.The first natural frequency of the second type specimen

2.3. The Stress of Specimens

The calculation of stress is performed at constant acceleration of 10g with respect to the frequency ratios at r = f/fn (f = excitation frequency, fn = natural frequency) = 0.9010, 0.9792, 1.0000, 1.0200, 1.0900 in finite element method software. Table 2&3 show the value of stress corresponding to each frequency ratio of the first and second type specimens.

Table 2: Stress value of the first type specimen

Freq. ratio r	Nat. Freq f_n (Hz)	Exc. Freq f (Hz)	Amplitude A (g)	Stress (MPa)
0.9010	41.29	37.2	10	248.7
0.9792	41.29	40.43	10	229.1
1.0000	41.29	41.29	10	197.2
1.0200	41.29	42.11	10	180.4
1.0900	41.29	45	10	164.8

Table 3: Stress value of the second type specimen

Freq. ratio r	Nat. Freq f_n (Hz)	Exc. Freq f (Hz)	Amplitude A (g)	Stress(MPa)
0.9010	43.79	39.45	10	238
0.9792	43.79	42.87	10	214.2
1.0000	43.79	43.79	10	189.5
1.0200	43.79	44.66	10	176.7
1.0900	43.79	47.73	10	159.1

2.4. Fatigue life of the specimens

Since the value of stress at each frequency ratio is known, thus the fatigue life of the structure at each frequency ratio can be manipulated. Table 4 and Figure 5 demonstrate the value of fatigue life in cycles and the graphic of fatigue life of the first type specimen. Again Table 5 shows the value of fatigue life in cycles and Figure 6 represents the fatigue life of the second type specimen respectively.

Table 4: Fatigue life of the first type specimen

Freq. ratio (r)	Fatigue Life (Cycles)
0.9010	12,214
0.9792	25,973
1.0000	103,045
1.0200	233,590
1.0900	536,387

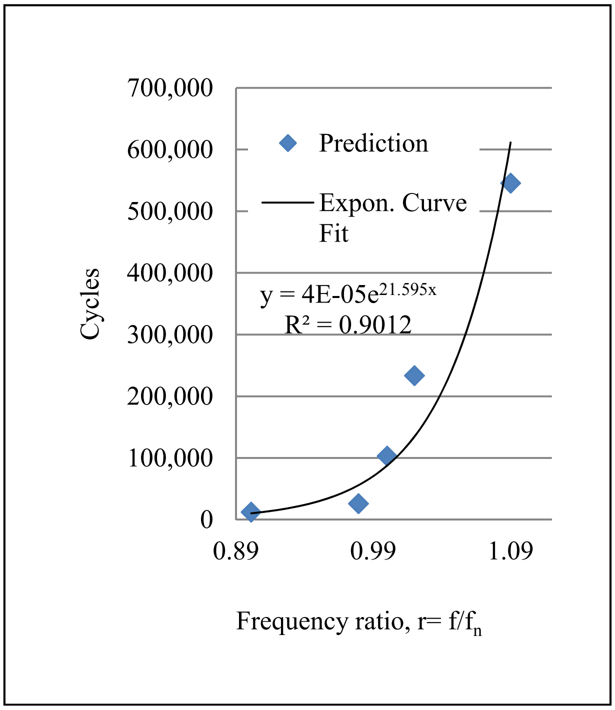

Fig.5. Graphic of fatigue life of the first type specimen

Table 5: Fatigue life of the second type specimen

Freq. ratio r	Fatigue Life (Cycles)
0.9010	18,297
0.9792	48,189
1.0000	148,599
1.0200	282,602
1.0900	741,283

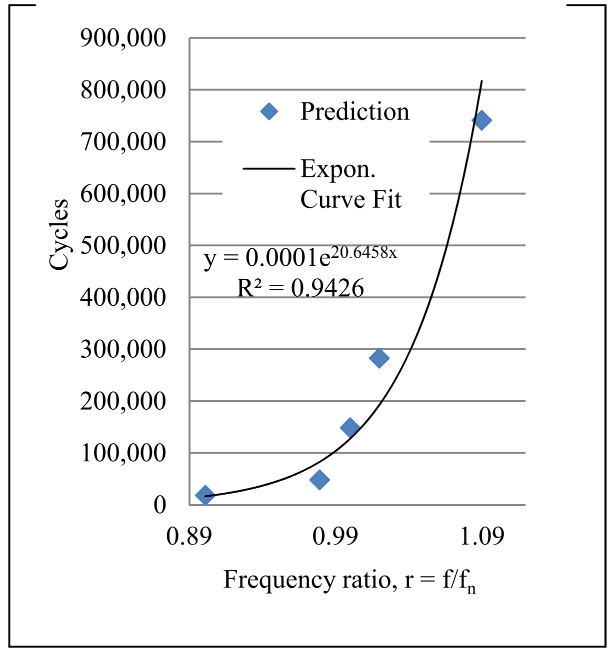

Fig. 6. Graphic of fatigue life of the second type specimen

3. EXPERIMENTAL RESULTS AND ANALYSIS

The experiment of fatigue testing is taken on the electrodynamics shaker. The excitation signal is in the form of sinusoidal with the amplitude of acceleration at level of 10g with the variation of frequency ratios, r = f/fn (f = excitation frequency, fn = natural frequency) = 0.9010, 0.9792, 1.0000, 1.0200, 1.0900.Table 5 and Figure 6 show the number of life cycles and graphic of the fatigue life of the first type specimen respectively. Whereas Table 6 and Figure 7 show the number of life cycles and graphic of the fatigue life of the second type of specimen.

The results obtained from experiment shows that at the smallest ratio frequency (r = 0.9010) i.e. the tested frequency is the smallest with respect to the constant acceleration (10g), the fatigue life is the shortest since the deformation at this point is the biggest ($A = (2*pi*f)^2*X$, where A is acceleration, f is frequency, X is deformation). Therefore, at the constant amplitude of acceleration, the fatigue life depends on the tested frequency if the frequency is small, the fatigue life is short and when the ratio frequency is high, the fatigue life is high as well.

Table 6: Fatigue life of the first type specimen

Freq. ratio r	Nat. Freq f_n (Hz)	Exc. Freq f (Hz)	Amplitude A (g)	Fatigue Life (Cycles)
0.9010	39.34	35.44	10.00	38,840
0.9792	39.34	38.52	10.00	70,957
1.0000	38.65	38.65	10.00	85,677
1.0200	39.15	39.93	10.00	104,812
1.0900	39.25	42.78	10.00	195,983

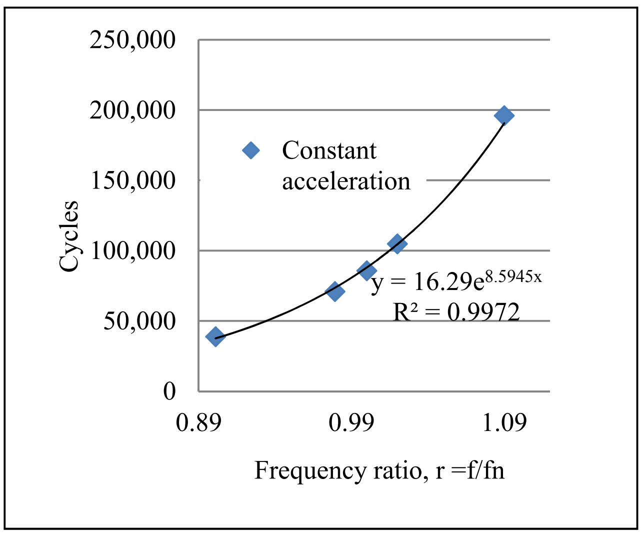

Fig.7. Graphic of fatigue life of the first type specimen

Table 7: Fatigue life of the second type specimen

Freq. ratio r	Nat Freq f_n (Hz)	Exc. Freq f (Hz)	Amplitude A (g)	Fatigue Life (Cycles)
0.9010	42.22	38.04	10	30,047
0.9792	41.12	40.27	10	62,295
1.0000	42.59	42.59	10	66,465
1.0200	41.97	42.81	10	90,988
1.0900	41.12	44.82	10	171,923

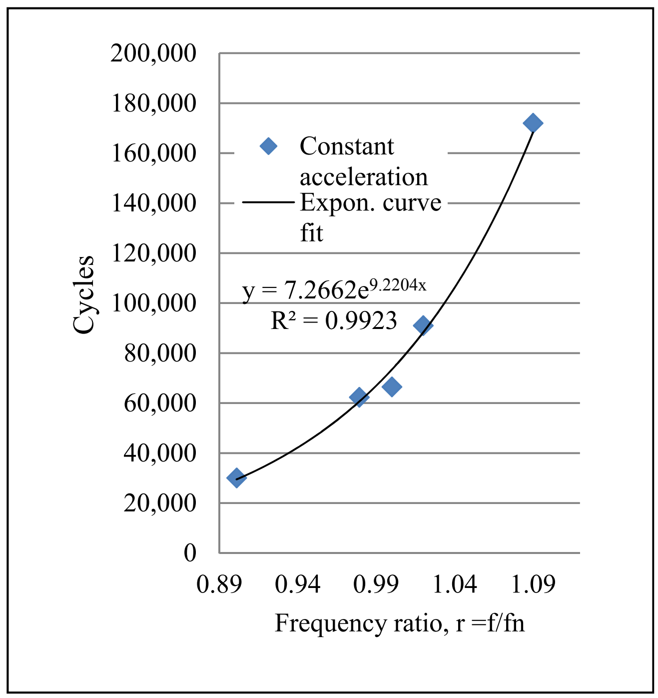

Fig.8. Graphic of fatigue life of the second type specimen

4. CONCLUSIONS

In this paper, the fatigue life is carried out in both finite element method and experiment. The fatigue life obtained from both finite element method and experiment are coherence each other's. The fatigue is increased when the frequency ratio increased while the amplitude of acceleration is constant.

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